BCM-003

APPLICATION

FOR

UNITED STATES LETTERS PATENT

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

Be it known that Miguel PEETERS a Belgian citizen, residing in Belgium and Raphael CASSIERS a Belgian citizen, residing in Belgium have invented certain improvements in a METHOD OF AND SYSTEM FOR OPTIMIZING THE CAPACITY OF A DIGITAL COMMUNICATION SYSTEM IN PRESENCE OF BOTH INTERNAL AND EXTERNAL NOISE of which the following description in connection with the accompanying drawing is a specification, like reference characters on the drawing indicating like parts in the figure.

METHOD OF AND SYSTEM FOR OPTIMIZING THE CAPACITY OF A DIGITAL COMMUNICATION SYSTEM IN PRESENCE OF BOTH INTERNAL AND EXTERNAL NOISE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not Applicable

REFERENCE TO MICROFICHE APPENDIX

[0003] Not Applicable

BACKGROUND OF THE INVENTION

[0004] The present invention relates to noise in digital communication systems, and more particularly, to distinguishing particular classifications of noise in a digital communication system and using those distinctions to determine an accurate noise margin.

[0005] The reliability of a digital communication channel is commonly expressed in term of Bit Error Rate (referred to herein as "BER"). A digital communication system is typically designed to provide a reliability level better than some worst-case reference level, further referred as BER_{req}, dependant on the type of service provided above this communication channel.

[0006] Digital signal processing theory shows that the bit error rate of a communication system is a function of the Signal power to Noise power Ratio (referred to herein as "SNR") at the input of the receiver. Let us call SNR_{req} the required SNR necessary to achieve a BER equal to BER_{req}. In order to provide a good quality of service, it is common practice to require that a communication system operate at an SNR exceeding SNR_{req} by some factor known in the art as Noise Margin (referred to herein as "m"). The Noise Margin is defined as the amount of external noise increase that the communication system can tolerate while still insuring a data transport

with a BER lower than BER_{req}. The Noise Margin m may be calculated as:

$$m = \frac{SNR}{SNR_{req}}$$

The noise margin is typically expressed in a logarithmic scale (e.g., in dB).

[0007] The noise present in a communication system can be classified according to its source. For example, the noise can theoretically distinguished as:

- The external noise (N_e) defined as the noise already present on the signal at the input of the receiver
- The internal noise (N_i) defined as the equivalent noise increase introduced by the non-ideal behavior of the receiver. This typically includes the receiver input noise, analog to digital converter noise and non-linear behavior, residual echo noise in duplex systems, residual inter-symbol interference, etc...

[0008] The noise margin required from a communication system only applies to the noise sources that are subject to variation over time. In many systems, the internal noise can be safely considered as being constant over the time, and therefore does not figure into the noise margin calculation. However, for the sake of simplicity, in many communication systems no distinction is made between internal and external noise in the computation of the noise margin. One disadvantage to computing noise margin this way is that the resulting noise margin may be unnecessarily large, which translates to sub-optimal system performance in areas such as data throughput, range or power consumption.

[0009] It is an object of the present invention to substantially overcome the above-identified disadvantages and drawbacks of the prior art.

SUMMARY OF THE INVENTION

[0010] The present invention describes a method to easily introduce the distinction of internal and external noise in the computation of the noise margin of a communication system, thereby improving the performance of this communication system. This improvement may either take the form of improved rate, reach or consumed power.

[0011] The foregoing and other objects are achieved by the invention which in one aspect comprises a method of optimizing a communication system for receiving and processing an input communication signal. The method includes selecting a first noise margin m to be applied against an external noise present on the input communication signal. The method further includes selecting a second noise margin m_i to be applied against an internal noise introduced on the communications signal by the communication system. The second noise margin is a predetermined function of the first noise margin. The method also includes calculating a virtual noise to signal ratio that is a combination of an external noise to signal ratio NSR_e, an internal noise to signal ratio NSR_i, the first noise margin and the second noise margin. The method further includes adjusting one or more system parameters so as to maintain the virtual noise to signal ratio at a predetermined margin above a required noise to signal ratio.

[0012] Another embodiment further includes distinguishing the external noise and the internal noise, and determining a contribution to a total noise from each of the external noise and the internal noise.

[0013] Another embodiment further includes distinguishing and determining the external noise and internal noise by first determining one or more system parameters associated with the communication system, then performing a first noise power measurement with no output signal being generated from an associated communication system transmitter, and while the communication system is receiving and decoding a known periodic signal. Next, performing a second noise power measurement while the associated communication system transmitter is generating output signals, and while the communication system is receiving and decoding a known periodic signal, then performing a third noise power measurement while the associated communication system transmitter is generating output signals, and while the communication system is receiving and decoding a pseudo-random signal. Then, the embodiment includes determining the external noise by subtracting a known receiver noise floor from the first power measurement, and determining the internal noise floor by subtracting the external noise from the third power measurement.

[0014] Another embodiment further includes calculating the virtual noise to signal ratio

as a sum of NSR_e, and a product of (i) a ratio of the second noise margin to the first noise margin and (ii) NSR_i, such that the virtual noise to signal ratio is substantially equal to

$$NSR_e + \frac{m_i(m)}{m} NSR_i \quad .$$

[0015] Another embodiment further includes adjusting the one or more system parameters, wherein the predetermined margin is substantially equal to the first noise margin m.

[0016] Another embodiment further includes selecting the first noise margin and the second noise margin such that the first noise margin is greater than or equal to the second noise margin for all time.

[0017] Another embodiment further includes selecting a target margin corresponding to the first noise margin at an initial time, and selecting a target internal margin corresponding to the second noise margin at an initial time. The target internal margin is a predetermined function of the target margin.

[0018] Another embodiment further includes selecting the first noise margin and the second noise margin such that the first noise margin remains stable in the presence of one or more measurement errors.

[0019] Another embodiment further includes, in a multiple carrier communication system, selecting a first noise margin and a second noise margin for each carrier channel, and adaptively equalizing the noise margins across all of the multiple carriers via real-time adjustment of the one or more system parameters.

[0020] Another embodiment further includes, in a multiple carrier communication system, selecting an internal noise margin that is a function of the mean external margin, i.e., the mean system margin.

[0021] Another embodiment further includes calculating the second noise margin m_i as a predetermined function of the first noise margin m, wherein the second noise margin m_i is given by (in dB):

$$
\begin{cases}
m_{dB} & m_{dB} \le 1.5 \\
\dfrac{2-1.5}{m_{t\arg et,dB}-1.5}(m_{dB}-1.5)+1.5 \quad for & 1.5 < m_{dB} \le m_{t\arg et,dB} \\
m_{dB}-m_{t\arg et,dB}+2 & m > m_{t\arg et,dB}
\end{cases}
$$

whereby m_i takes on different functions of m according to different ranges of m.

[0022] In another aspect, the invention includes an apparatus for optimizing a communication system for receiving and processing an input communication signal. The apparatus includes a parameter monitoring component for monitoring one or more system parameters associated with the communication system. The apparatus further includes a noise monitoring component for measuring noise power in the communication system. The apparatus also includes a virtual noise processor for calculating a virtual noise to signal ratio that is a combination of an external noise to signal ratio NSR_e, an internal noise to signal ratio NSR_i, a first noise margin and a second noise margin. The apparatus also includes a system parameter processor for adjusting one or more system parameters so as to maintain the virtual noise to signal ratio at a predetermined margin above a required noise to signal ratio.

[0023] In another embodiment, the noise monitoring component distinguishes the external noise and the internal noise, and determines a contribution to a total noise from each of the external noise and the internal noise.

[0024] In another embodiment, the noise monitoring component distinguishes and determines the external noise and internal noise by determining one or more system parameters associated with the communication system, and by performing a first noise power measurement with no output signal being generated from an associated communication system transmitter, and while the communication system is receiving and decoding a known periodic signal. The noise monitoring component further distinguishes and determines the external noise and internal noise by performing a second noise power measurement while the associated communication system transmitter is generating output signals, and while the communication system is receiving and decoding a known periodic signal. The noise monitoring component further distinguishes and

determines the external noise and internal noise by performing a third noise power measurement while the associated communication system transmitter is generating output signals, and while the communication system is receiving and decoding a pseudo-random signal, and by determining the external noise by subtracting a known receiver noise floor from the first power measurement. The noise monitoring component further distinguishes and determines the external noise and internal noise by determining the internal noise floor by subtracting the external noise from the third power measurement.

[0025] In another embodiment, the virtual noise processor calculates the virtual noise to signal ratio as a sum of NSR_e, and a product of (i) a ratio of the second noise margin to the first noise margin and (ii) NSR_i, such that the virtual noise to signal ratio is substantially equal to

$$NSR_e + \frac{m_i(m)}{m} NSR_i \quad .$$

[0026] In another embodiment, the system parameter processor adjusts the one or more system parameters, and the predetermined margin is substantially equal to the first noise margin m.

[0027] In another embodiment, the virtual noise processor selects the first noise margin and the second noise margin such that the first noise margin is greater than or equal to the second noise margin for all time.

[0028] In another embodiment, the virtual noise processor selects a target margin corresponding to the first noise margin at an initial time, and selects a target internal margin corresponding to the second noise margin at an initial time, wherein the target internal margin is a predetermined function of the target margin.

[0029] In another embodiment, the noise processor selects the first noise margin and the second noise margin such that the first noise margin remains stable in the presence of one or more measurement errors.

[0030] In another embodiment, the virtual noise processor selects, in a multiple carrier communication system, a first noise margin and a second noise margin for each carrier channel, and adaptively equalizes the noise margins across all of the multiple carriers via real-time

adjustment of the one or more system parameters.

[0031] In another embodiment, the virtual noise processor calculates the second noise margin m_i as a predetermined function of the first noise margin m, wherein the second noise margin m_i is given by (in dB):

$$\begin{cases} m_{dB} & m_{dB} \leq 1.5 \\ \dfrac{2-1.5}{m_{t\arg et,dB}-1.5}\left(m_{dB}-1.5\right)+1.5 \quad for & 1.5 < m_{dB} \leq m_{t\arg et,dB} \\ m_{dB}-m_{t\arg et,dB}+2 & m > m_{t\arg et,dB} \end{cases}$$

whereby m_i takes on different functions of m according to different ranges of m.

BRIEF DESCRIPTION OF DRAWINGS

[0032] The foregoing and other objects of this invention, the various features thereof, as well as the invention itself, may be more fully understood from the following description, when read together with the accompanying drawings in which:

[0033] FIG. 1 shows a block diagram of one embodiment of an apparatus for optimizing a communication system for receiving and processing an input communication signal.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] One embodiment of the method and system described herein relies on the assumption that the associated receiver is capable of making the distinction between the external noise affecting the received signal, and the internal noise that its own non-ideal implementation introduces on the signal. In other embodiments for which a precise distinction cannot be made, a coarse estimation of the internal noise may be used.

[0035] As an example, the following strategy could be followed to distinguish, in a

tranceiver, the respective contribution of internal and external noise sources in the measured noise power:

1. Determine all of the relevant transceiver parameter settings (e.g., transmitter gain, receiver gain, equalizer coefficients, echo canceller coefficients, etc.).
2. Perform a first measurement of the noise power, N_1, while the transmitter is silent and the receiver decodes a known periodic signal. Only external noise and the known receiver noise floor are measured:

$$N_1 \cong N_e + N_{RxNoiseFloor} \quad (1)$$

3. Perform a second measurement of the noise power, N_2, whilst the transmitter is generating signals, and the receiver decodes a known periodic signal. In addition to the previous measurement, the echo of all transmitter noises (both residual echo-canceller noise and non-linear distortion noise) are present:

$$N_2 \cong N_1 + N_{TxEchoNoise} \quad (2)$$

4. Perform a third measurement of the noise power, N_3, whilst the transmitter is generating signals, and the receiver decodes a known pseudo-random signal. In addition to the previous measurement, the inter-symbol interference equivalent noise is measured:

$$N_3 \cong N_2 + N_{ISInoise} \quad (3)$$

[0036] From the above measurements, we can derive an approximation of the internal and external noise sources:

$$N_e \cong N_1 - N_{RxNoiseFloor} \quad (4)$$

$$N_i \cong N_{RxNoiseFloor} + N_{TxEchoNoise} + N_{ISInoise} \quad (5)$$

$$N = N_e + N_i \quad (6)$$

[0037] It is often easier to handle Signal to Noise Ratio (SNR) values, or equivalently Noise to Signal power Ratio (NSR) values, than absolute noise or signal power, we can re-write (6) relative to the received signal power:

$$NSR = NSR_e + NSR_i \quad (7)$$

[0038] The method and system described herein proposes an easy way to cope with the

requirement that a different noise margin should be taken on the internal and on the external noise sources. Even if the internal noise is assumed to be constant, it may be necessary to take some margin against this noise as well, such as to insure a nominal operation at a BER level lower than BER_{req} or/and to insure that small variation on the internal noise do not cause the noise the system to exceed BER_{req}.

[0039] If we call m and m_i respectively the required noise margins on external and internal noise, a virtual noise N_V may be defined such that:

$$m\,N_V = m\,N_e + m_i(m)N_i \qquad (8)$$

Alternatively:

$$NSR_V = NSR_e + \frac{m_i(m)}{m} NSR_i \qquad (9)$$

[0040] The basic idea behind the method and system described herein is to replace in the design of a communication system the use of real SNR values by a virtual SNR value, SNR_V, as given by equation (9). SNR_V incorporates one margin, m, against the external noise, and a different margin, m_i, against the internal noise. By choosing a margin on internal noise lower than the margin on external noise, this virtual SNR is larger than the real SNR. Nevertheless, a design based on the virtual SNR still insures that the required noise margin is achieved against the external noise sources.

[0041] When the external noise varies, the margin computed from this virtual SNR varies accordingly:

$$m_{dB} = 10\log_{10}\left(\frac{NSR_{req}}{NSR_V}\right) \qquad (10)$$

[0042] It is desirable to also let the internal margin m_i be a function of the instantaneous margin m, such that:

- the margin m_i taken against internal noise is always lower than the margin taken against external noises, i.e., $m_i(m) \le m$
- at initialization time, a target margin m_0 taken against external noises corresponds to the

wanted target internal margin : $m_i(m_0) = m_{i0}$

- the computed margin is stable, even in the presence of some measurement errors

[0043] To analyze under which conditions this scheme will lead to a stable system behavior, consider the following limit cases.

[0044] First, consider a system with no internal noise. In this trivial case, equation (8) reduces to:

$$NSR_V = NSR_e, \tag{8'}$$

i.e., the virtual SNR is equal to the external SNR.

[0045] Next, consider a system limited by internal noises, but without error on the estimation of NSR_i (i.e., $NSR=NSR_i$). Assume a linear dependency of the noise margin against internal noise with respect to the noise margin against the virtual noise computed:

$$m_{i,dB} = a.m_{dB} + b \tag{11}$$

[0046] Equations (9) and (10) represent an iterative process. In order to determine the conditions for which the process converges and the corresponding convergence values, it is necessary to evaluate equations (9) and (10) with $NSR_e = 0$. Doing so gives the iteration equation:

$$m_{k+1,dB} = m_{k,dB} + m_{i,dB}^{real} - m_{i,dB}(m_k) \tag{12}$$

where

$$m_{i,dB}^{real} = 10\log_{10}\left(\frac{NSR_{req}}{NSR_i}\right)$$

represents the real margin on the internal noise.

[0047] Using the assumed linear dependency given by equation (11), the iteration equation (12) can be rewritten:

$$m_{k+1,dB} = m_{k,dB} + m_{i,dB}^{real} - (a.m_{k,dB} + b) \tag{13}$$

[0048] This system as an equilibrium point if a<>0 for

$$m_{dB} = \frac{m_{i,dB}^{real} - b}{a} \tag{14}$$

[0049] To determine under which condition this equilibrium point is stable, evaluate the convergence of the error towards the mean value, which gives:

$$e_{k+1} = (1-a).e_k \tag{15}$$

[0050] The error is thus converging to 0 if $|a|<1$. In particular, if a=0 (i.e., if the margin taken against internal noise does not depend on the margin against the virtual noise), then the system does not converge. Further, if a=1, the margin converges in one iteration to its equilibrium point.

[0051] One proposed formula for $m_i(m)$ is

$$m_{i,dB} = \begin{cases} m_{dB} & m_{dB} \leq 1.5 \\ \dfrac{2-1.5}{m_{t\arg et,dB} - 1.5}(m_{dB} - 1.5) + 1.5 \quad for & 1.5 < m_{dB} \leq m_{t\arg et,dB} \\ m_{dB} - m_{t\arg et,dB} + 2 & m > m_{t\arg et,dB} \end{cases} \tag{16}$$

This formula gives an internal margin m_{i0} of 2 dB for the initial target margin.

[0052] One embodiment of the method and system described herien may be used in a multi-carrier transmission system, in which a set of N carrier signals are used to convey the information bits, where N is an integer greater than or equal to two. The SNR, and hence the noise margin, is monitored on each carrier independently. In some embodiments, the noise margin is adaptively equalized across all sub-carriers via techniques known in the art, such as on-line (e.g., real time) adjustment of the gain and bit loading of each sub-carrier. The proposed method to handle different margin requirements against internal and external noises allows such margin equalization algorithm to remain unchanged, and to still optimally equalize the margin according to this new constraint.

[0053] The basic equations (8), (9) and (10) derived herein for a single carrier system can

easily be extended to the multi-carrier case, as follows:

$$\overline{m}\,N_V^l = \overline{m}\,N_e^l + m_i^l(\overline{m})N_i^l \quad (8b)$$

$$NSR_V^l = NSR_e^l + \frac{m_i^l(\overline{m})}{\overline{m}} NSR_i^l \quad (9b)$$

$$\overline{m}_{dB} = \frac{10}{N}\sum_{l=0}^{N-1}\log_{10}\left(\frac{NSR_{req}^l}{NSR_V^l}\right) \quad (10b)$$

The superscript l is used to identify carrier-dependant entities. Equations (8b), (9b) and (10b) demonstrate that for a multi-carrier case, the internal noise margin $m_i^l(\overline{m})$ is solely a function of the mean margin $\overline{m}$.

[0054] Considering again the behavior of a system with no external noise, we can derive the iteration equation for the mean margin:

$$\overline{m}_{k+1,dB} = \overline{m}_{k,dB} + \overline{m}_{i,dB}^{real} - m_{i,dB}(\overline{m}_k) \quad (12b)$$

with

$$\overline{m}_{i,dB}^{real} = \frac{10}{N}\sum_{l=0}^{N-1}\log_{10}\left(\frac{NSR_{req}^l}{NSR_i^l}\right)$$

the real mean margin on the internal noise.

[0055] In one embodiment, the dependence of the internal margin m_i on the mean margin is linear in dB. The iteration equation (12) can then be rewritten as:

$$\overline{m}_{k+1,dB} = \overline{m}_{k,dB} + \overline{m}_{i,dB}^{real} - (a.\overline{m}_{k,dB} + b) \quad (13b)$$

[0056] This system has an equilibrium point if a<>0 for

$$\overline{m}_{dB} = \frac{\overline{m}_{i,dB}^{real} - b}{a} \quad (14b)$$

[0057] This formula shows that the relationship between m_i and m holds for the mean

margin on the internal noise and the mean margin at the equilibrium point. The stability condition remains the same as the one previously derived.

[0058] The reported margin on one tone is given by:

$$m = \frac{\overline{m}}{m_i(\overline{m})} m_i^{real} \tag{20}$$

with m_i^{real} the real margin on this tone to internal NSR. This equations implies that:

- the reported margin depends on the mean margin. So, if the real internal margin is constant, the margin can change due to mean margin change. In fact, if the relationship is linear in dB, we show
$m_{new,dB} = m_{old,dB} + (1-a).\alpha$
with α the change in dB on the mean margin. This dependence vanishes if a=1.

- a change in dB on the internal margin with a constant mean margin, for example due to a carrier-dependant gain adjustment, induces the same change in dB on the reported margin.

[0059] In general, a method and system is disclosed herein for handling different noise margin constraints on internal and external noise components in a communication system, thereby improving the system performance parameters with a minimal complexity impact. The stability of the proposed scheme has been analyzed under particular limit conditions, and a specific implementation is proposed, which provides up to 4dB improvement in system performances. The method and system disclosed herein is particularly useful for a multiple carrier system, and this disclosure analyzes how such system behaves when one embodiment of the method and system is incorporated.

[0060] FIG. 1 shows a block diagram of one embodiment of an apparatus 100 for optimizing a communication system 102 for receiving and processing an input communication signal. The apparatus 100 includes a parameter monitoring component 104 that monitors the system parameters associated with the communication system 102. The apparatus 100 further includes a noise monitoring component 106 that receives input from the system 102 and the

parameter monitoring component 104 and distinguish and determine the contributions of the external noise and the internal noise to the overall noise. A virtual noise processor 108 receives the external and internal noise values from the noise monitoring component 106, and calculates a virtual noise value from the noise components, along with separate external and internal noise margins, as disclosed herein. A system parameter processor 110 receives the virtual noise value from the virtual noise processor 108 and adjusts one or more system parameters so as to maintain the virtual noise to signal ratio at a predetermined margin above the require noise to signal ratio (i.e., to maintain the desired noise margin).

[0061] The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of the equivalency of the claims are therefore intended to be embraced therein.